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The Role of Atomic Repertoires in Complex Behavior

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Evolution and reinforcement shape adaptive forms and adaptive behavior through many cycles of blind variation and selection, and therein lie their parsimony and power. Human behavior is distinctive in that this shaping process is commonly "short circuited": Critical variations are induced in a single trial. The processes by which this economy is accomplished have a common feature: They all exploit one or more atomic repertoires, elementary units of behavior each under control of a distinctive stimulus. By appropriate arrangements of these discriminative stimuli, an indefinite number of permutations of atomic units can be evoked. When such a permutation satisfies a second contingency, it can come under control of the relevant context, and the explicit arrangement of discriminative stimuli will no longer be required. Consequently, innovations in adaptive behavior can spread rapidly through the population. A consideration of atomic repertoires informs our interpretation of generalized operants and other phenomena that are otherwise difficult to explain. Observational learning is discussed as a case in point.

Key words: atomic repertoire, imitation, observational learning, rule-governed behavior, selectionism, origins of variability in behavior

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Natural selection is a process of wonderful simplicity, power, and scope. It explains, among other things, how lineages of organisms can track changes in environmental contingencies without knowing in advance how those contingencies will change. Whether the environment cools or warms, whether predators become faster, weaker, or more cunning, whether potential mates become more fastidious, lineages of organisms will emerge that will be well suited to the new order of things. Natural selection offers a parsimonious explanation of adaptation to environmental change when the rate of such change can be matched by corresponding changes in the distribution of heritable variations. But natural selection cannot directly explain adaptation to features of the environment that change rapidly over generations or that are inconsistent within the lifetime of an individual organism, because in such cases the pace of heritable variation cannot keep up with the pace of environmental change.

Fortunately, natural selection has hit upon a solution to the problem of rapid variation in environmental contingencies: susceptibility to reinforcement by certain kinds of consequences. The behavior of a mobile organism can change the environment, change its relation to the environment, or move the organism to a more favorable part of the environment, and it can do so more and more effectively through the reinforcement of variations in behavior. Moreover, like natural selection, programs of contingencies can accumulate small variations into large effects. In classroom demonstrations, it is an easy matter to get a rat to press a lever with unusual force by gradually increasing the mass of a counterweight or to get a pigeon to time pauses between successive pecks with considerable precision by gradually refining the temporal contingencies of reinforcement. Presumably skilled behavior in natural environments is shaped in analogous ways. As long as variation in behavior is sufficient to meet the demands of new

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contingencies, the distribution of behavior will tend to shift accordingly. Thus variation is the heart of both evolution by natural selection and shaping by reinforcement, and the selection of ultimately blind variations is a nonteleological explanation of adaptive complexity in both biological forms and the behavior of organisms.[1] This common feature of natural selection and learning has occurred to several observers, apparently independently (e.g., Baldwin, 1895, 1909/1980; Campbell, 1956; Pringle, 1951; Skinner, 1953, 1981). The power and parsimony of selection processes buttress our confidence that principles of learning are sufficient to account for complexity in behavior.

Even though the course of evolution is seldom known in detail, scientists unanimously accept that natural selection and related evolutionary processes are sufficient to explain the countless biological forms observed in nature, because in every case the shaping effect of changing contingencies of selection is plausible. However, many scientists reject the analogous claim that adaptive complexity in behavior can be fully explained by the reinforcement of successive approximations of the terminal behavior. Some reasons for this rejection may be ideological, but surely a major reason is that even a cursory glance at human behavior reveals that the claim is patently false: Novel forms of adaptive behavior often appear in a single trial. Indeed the gradual shaping of complex behavior is relatively rare in adult humans. We can tell a friend to meet us at the Town Hall at 6:00 p.m. and be reasonably sure that he will be there within a few minutes of the appointed hour, even if he has never been there before. But the feat will not be accomplished by reinforcing successive approximations of the target behavior. Perhaps he will consult a map, ask directions of a passerby, announce his destination to a taxi driver, or punch coordinates into a satellite-guided navigational device, but we do not expect him to wander aimlessly until someone tells him he is getting warmer or getting colder, as in the children's game of hunt-the-slipper. In a world in which plenty of people and their electronic gadgets already know how to get to the Town Hall, the surest way of getting there is to consult them. In much human behavior, the process of shaping is short circuited by guidance from other people or their surrogates (cf. Andronis, 1991).

ATOMIC REPERTOIRES

To capture this feature of human behavior, Skinner (1953, 1957, 1963/1969, 1966) introduced the distinction between rule-governed and contingency-shaped behavior:

> Society codifies its ethical, legal, and religious practices so that by following a code the individual may emit behavior appropriate to social contingencies without having been directly exposed to them. Scientific laws serve

[1] I say "ultimately" blind because it is possible that variation and stasis themselves could be the object of selection, possibly through redundant genetic mechanisms. We are more likely to be born with extra fingers than extra eyes. Neither optics, gravity, nor the density of air change in meaningful ways over evolutionary time, but rainfall and temperature can change dramatically from one year to the next with corresponding changes in the distribution and composition of food. Consequently one might expect some physiological systems, such as those responsible for vision, balance, and flight, to be more stable than others, such as those responsible for gathering and ingestion of food. That is, the beak of the finch might be more variable than the eye of the finch. But if that is true, it is adaptive only in a world that is like the past. In the absence of a designer, the first instance of adaptive variation must necessarily be blind.In the case of behavior, skilled problem solvers know the value of varying their behavior as an explicit strategy, but that strategy itself must have been discovered by chance, or it was learned from someone else. Such a strategy could be passed from person to person, but the origin of the first instance must have been the product of accidental variation.

a similar function in guiding the behavior of scientists. (Skinner, 1963/1969, p. 123)

Skinner did not define the term *rule-governed behavior* precisely, as he seemed to have regarded it as self-evident, but he used it interchangeably with the expression *contingency-specifying stimuli*. But although a rule may specify a contingency, it need not. A more fundamental analysis is possible. In the behavior analysis literature, much has been written about the special properties of rule-governed behavior (e.g., Catania, 2007; Cerutti, 1989; Chase & Danforth, 1991; Schlinger, 1990; Zettle & Hayes, 1982). But for present purposes, rule-governed behavior is distinctive primarily because it illustrates the role of atomic repertoires in human behavior. The latter term is taken from Skinner (1957), but he did not offer it as a technical term, as I do here. By *atomic repertoire* I mean a set of fine-grained units of behavior, each under control of a distinctive stimulus, that can be evoked in any permutation by the arrangement of corresponding stimuli. Like letters on a page that can be arranged to display a great variety of expressions, atomic responses can be arranged to meet a great variety of contingencies. Examples of atomic repertoires include rule-governed behavior, imitation, echoic behavior, textual behavior, transcription, and tacting, among others. The grain of such units depends on one's history of discrimination training and is therefore idiosyncratic. The important feature of atomic repertoires is that they permit the induction of a criterion variation in behavior in a single trial, or in a few.

As noted above, natural selection and reinforcement ordinarily exploit blind variation, and many such variations will not meet the relevant criterion for selection. This sheer wastefulness and inefficiency make the principles powerful: As long as the supply of variants is inexhaustible, and as long as plenty of time is available, selection processes will yield adaptive complexity eventually, but only by ruthlessly winnowing out all variations that do not measure up to criterion. But atomic repertoires permit directed variation. If one member of a group stumbles upon an adaptive response through blind variation, the adaptation can be transmitted throughout the group by directed variation, without shaping. Thus, in human affairs the importance of atomic repertoires is incalculable, for they are the bricks and mortar from which directed variation is built.

In the case of rule-governed behavior, the atomic repertoire is a set of elementary responses under verbal control. If we want to telephone a friend, we do not randomly enter 10-digit numbers until he answers the phone; rather, we ask someone for his telephone number and enter it correctly the first time. The atomic response is the pressing of a key under control of a corresponding verbal antecedent, and the temporal arrangement of verbal stimuli specifies the sequence in which these responses must be emitted. We consult cookbooks, instruction pamphlets, and do-it-yourself manuals for the very reason that they break complex responses into atomic elements, and the order of the instructions specifies the order in which the responses must be executed: "Screw the 8 screw into the pilot hole provided." "Set the power switch to Off before installing battery." "Knit two, purl two for three rows." In each case a sequence of relatively elementary units of behavior is under the control of an arrangement of instructions, not the natural contingencies, and they typically appear correctly in a single trial. Even if instructed performance does not emerge correctly in a single trial, it is likely to do so more rapidly than when the behavior is contingency shaped (Danforth, Chase, Dolan, & Joyce, 1990).

Multiple Control and Atomic Repertoires

When instructed to do so, most people can raise or lower their hand, take a step forward or back, turn to the right or left, look up, look down, and so on. This relatively small set of discriminated operants can be pressed into service in a wide variety of contexts to satisfy a wide variety of novel contingencies. Moreover, the resulting topography of response can often be exquisitely precise because behavior is commonly multiply determined (Michael, Palmer, & Sundberg, 2011; Skinner, 1957). That is, the relevant behavioral atom need not be fine grained if the response is constrained by other variables. The case of pressing numbers on a keypad illustrates the point: The behavior is partly under control of a verbal stimulus and partly under control of the stimulus properties of objects in the world (the keypad). The verbal instruction is followed quite precisely only because the location of the keys themselves shares control over the topography of the response. That is, we modulate our own behavior in the process of executing it according to continuous feedback from objects in the world. If our finger strays and threatens to miss the seven key, we correct its trajectory. When told to look up and to the right at a green tile, our gaze is determined partly by the location of the tile as a discriminable target, not simply by the verbal instruction. Thus the actual atomic repertoire under verbal control is typically quite coarse; we can see this clearly when control by objects in the environment is eliminated: "Raise your left hand four inches." "Hold your head still; then rotate your eyes 20 degrees to the right and 15 degrees up." Most of us simply lack the history of differential reinforcement to be able to move our bodies in the required ways in any more than a crude approximation of the specified topography. We can see then that the command "Look up and to the right at the green tile" is not simply a discriminative stimulus that evokes a precise movement of our eyes up and to the right. Rather, it evokes a relatively crude response of scanning; in addition, it is a motivating operation that establishes the green tile as a reinforcer: The behavior of orienting to it will be executed more swiftly on subsequent trials. The cogency of the claim that rule-governed behavior is commonly under multiple control becomes clearer as the task becomes more difficult: To orient to a green tile may seem to require no scanning at all, if it is the only salient object in our visual field, but if it is just one in a mosaic of hundreds of colored tiles, the imprecise nature of the verbally controlled atomic response of "looking up and to the right" is revealed. Because we have long histories of responding discriminatively to features of our environment, a relatively coarse repertoire of atomic responses is adequate to generate behavior of requisite precision in many novel contexts.

The Grain of the Atomic Repertoire

The role of differential training in determining the grain of the atomic repertoire becomes clear when we compare those who have long histories of such differential training, such as gymnasts, artists, military cadets, and ballet dancers, with those who lack such histories. A ballet instructor can issue a complex command, such as "four frappés front, four frappés side, flic flac en dehors, petit battement, repeat en dedans," and a room full of trained ballerinas will all execute the command with remarkable precision, with little, if any, feedback from objects in the environment. Only under conditions of such special training, as in sports, dance, and military drills, do people acquire precise movements under verbal control, but a coarse-grained repertoire is sufficient for many purposes. An atomic repertoire under verbal control is usually acquired through a history of social reinforcement, that is, a history of being told what to do by parents, teachers, siblings, and friends. The grain of the atomic repertoire depends on the details of these interactions and will be somewhat different from one person to another.

When a sequence of responses under instructional control is executed, it commonly has some practical effect. If we are dialing the numbers on a safe under instructional control, the safe opens; if we have closed the choke, opened the throttle, and are tugging on the rope of a lawnmower under instructional control, it will start. Under such conditions a common topography of response satisfies two contingencies: the social contingency of rule following and the nonsocial contingency of the physical world. Once executed and reinforced by natural consequences, the pattern of responses can come under control of the natural contingencies.

Animal Models

The critical features of rule-governed behavior can be demonstrated in a laboratory animal. In a demonstration experiment, a student trained two atomic responses in a rat: In the presence of a high tone, moving forward was reinforced; in the presence of a low tone, stopping and turning were reinforced. In a subsequent task in an eight-arm radial maze, in which food would be delivered when the rat reached the end of a randomly chosen arm, the rat behaved perfectly under instructional control. In the central chamber, in the presence of the low tone, he would stop and turn. When he faced the correct arm, the student would change the tone, and the rat would dart down that arm and collect a pellet of food. The analogy with dialing a telephone number under instructional control is precise. In performing animals, farm animals, and service animals, atomic responses are commonly trained to the verbal stimuli of the trainer, or to arbitrary stimuli such as a whistle, or a the tap of the reins. Performance in multiple schedules and chained schedules (e.g., Ferster & Skinner, 1957; Snodgrass & McMillan, 1989) illustrates sequential control of behavior by a corresponding presentation of stimuli, but they are seldom deployed for the purpose of generating new strings of responses that satisfy novel contingencies on the first trial.

Analogy with Protein Synthesis

The generation of novel permutations of atomic responses by an arrangement of corresponding discriminative stimuli is analogous to the synthesis of proteins by the ribosomes of cells. A strand of messenger RNA is a string of nucleotide codons, each of which specifies a particular amino acid. The ribosome "reads" each codon in sequence, brings in the specified amino acid, and links it to the other amino acids to form a protein. Once the protein has been completed, it hangs together as a unit independent of the strand of RNA that specified it. The elegance of the process lies in its economy: A small set of nucleotides can generate a vast number of proteins because they can be arranged in an indefinite number of permutations. So it is with atomic repertoires. Virtually any string of atomic responses can be specified by a small set of instructions, and once the responses have occurred in the correct sequence, they may hang together as a unit under control of prevailing contingencies. For example, once we have correctly operated a bread machine under control of an instruction manual, we can do so in the future without the manual. That instructed variation should occur at the most fundamental of biological processes is a testimony to its economy and power.

OTHER EXAMPLES OF ATOMIC REPERTOIRES

Imitation

Most people acquire a versatile repertoire of imitative responses through childhood games and explicit instruction, but mainly simply through countless unprogrammed contingencies. For a child facing a novel circumstance, the surest way to a happy result is to do what others do. As in the case of rule-governed behavior, when one member of a group stumbles upon an adaptive response, other members can acquire the response in one trial, or just a few. The rules of games and other social rituals are often easier to learn through imitation than from reading the rules or consulting a book of etiquette. In foreign countries we usually profit from imitating the behavior of others in airports, subways, and restaurants.

As in rule-governed behavior, even a crude imitative repertoire can be effective when the behavior in question is under multiple control of a model and some other aspect of the environment. It is easier to imitate a cook than a gymnast, in part because of the constraints imposed by the measuring cups, baking dishes, and cutlery of the cook's trade. (Gibson, 1977, called these constraints the *affordances* of objects.) For this reason, careful studies of imitation in young children avoid studying imitative responses that manipulate objects (e.g., Erjavec & Horne, 2008; Erjavec, Lovett, & Horne, 2009; Horne & Erjavec, 2007; Lovett, 2008). Simply making an object salient by manipulating it might potentiate similar behavior in an observer apart from any tendency to imitate.

Except when under multiple control, the grain of imitative behavior is typically coarse. Mere form is hard to imitate for at least two reasons: First, formal properties of behavior are important only insofar as they determine function. Because there are many variations in topography of response that will fill a bucket, carry a bag of groceries, or scoop flour, tight topographical control of imitative behavior is seldom shaped. Second, similarity in topography between a model and an imitator is often hard to assess from a single point of view. That is, from our own point of view, our behavior often looks different from the behavior of a model even when it is a faithful copy.

Like rule-governed behavior, imitative behavior short circuits the shaping process by inducing criterion variations in behavior. It is different from rule-governed behavior in that rules are usually formulated at some cost to the rule giver for the benefit of the rule follower; in imitation, the model may have no interest at all in being imitated and may prefer not to be. Willingly or not, the model who pursues his own interests effectively can induce comparable behavior in others with the requisite atomic repertoire.

Echoic Behavior

Echoic behavior is a special case of imitative behavior, special because people with normal hearing can hear themselves speak immediately and faithfully. This permits the shaping of much finer grained response topography than other imitative behavior, because any discrepancy between the echoic response and the antecedent stimulus is relatively conspicuous. In this respect, vocal behavior is superior to signing. The emission of normative speech requires precise control and coordination of tongue, lips, throat, jaw, diaphragm, and larynx, and this is achieved through automatic shaping. Children who are already discriminating listeners can detect discrepancies between their speech and that of others, and achieving parity with the practices of the verbal community is typically reinforcing (Donahoe & Palmer, 1994/2004; Palmer, 1996, 1998). Such fine-grained control is required because slight changes in response topography will produce different speech sounds, and unlike much other imitative behavior, the topography of vocal behavior is not supported by objects in the environment. The precision of stimulus control in echoic behavior is revealed by our inability to echo speech in foreign languages, particularly when the phonemes of that language differ from those of our own.

The fine grain of echoic behavior permits people to faithfully echo a nearly unlimited number of response sequences in their own language. As a consequence, complex verbal forms can spread with great speed throughout a verbal community, an effect that is amplified by television, radio, and the Internet; a single speaker can modify the repertoire of many listeners simultaneously. Notice the savings: Imagine shaping the response "Garibaldi" in just one person by reinforcing successive approximations of the name from undifferentiated vocal behavior. Because shaping exploits blind variation, it is impossible to shape the behavior of two organisms simultaneously with the same schedule of reinforcement. Thus to teach a single novel verbal response to everyone in a verbal community through the reinforcement of successive approximations would be a monumental task, but it is a trivial matter to do so for those with atomic echoic repertoires.

Textual Behavior

Characters on a page control textual responses (reading), and the atomic nature of our textual repertoire is revealed by our ability to sound out unfamiliar texts. It may be that you have never encountered the name Garibaldi before, but it has now been emitted as a presumably covert textual response. As I have pointed out elsewhere (Palmer, 2008), echoic and textual responses transduce verbal stimuli into verbal responses. If, as usually happens, such responses are embedded in contingencies of reinforcement, these responses acquire strength in the relevant context. Consequently we are able to learn through reading and listening, even though an observer would notice no three-term contingencies. Both textual and echoic repertoires facilitate the acquisition of indefinitely long sequences of novel forms of behavior without shaping. Like echoic behavior, textual behavior tends to be fine grained, because verbal contingencies shape up sharp distinctions between similar characters and between similar speech sounds.

Transcriptive Behavior

Transcription—writing from dictation, copying from texts, sending smoke signals, using semaphore, Morse code, or encrypted messages—typically requires one or more atomic repertoires. Many people can write in cursive or block letters and can type on a keyboard. Some can write in italic or in different alphabets, such as Arabic, Hebrew, or Cyrillic, or in pictograms, such as Chinese characters. The atomic nature of such behavior is revealed in the ability to write plausible transcriptions of unfamiliar words. Transcription is important when the script serves as a controlling stimulus for subsequent textual behavior by the writer or by others, but it can also serve to strengthen relevant verbal behavior at the time of writing. That is, a student who takes notes may learn a lesson more thoroughly than one who does not, even if the notes are not subsequently reviewed. The very behavior of transcription presumably alters the student's repertoire in the relevant context.

Transcription is typically explicitly shaped by instructional contingencies and maintained by generalized social reinforcers. Like echoic behavior, but unlike imitation and rule-governed behavior, the topography of evoked transcriptive behavior seldom has an important effect on the nonverbal environment; its importance lies in its effect on readers. Consequently, a secondary source of reinforcement for the behavior is uncertain and can be long delayed. A monk might copy a manuscript from an ancient scriptorium without being able to understand a word of it, just as the telegraph clerk of more recent times was sometimes no more than a biological transistor, transforming an encrypted message into a useful form but remaining unchanged by it.[2] The secondary contingency comes into effect when the transcript is read, often at a later time, by someone who can take effective action as a result. The importance of transcription is that it transforms a transient stimulus into a relatively enduring one, one that can control the behavior of indefinitely many people over indefinite passages of time.

Tacting

In some respects a tact repertoire is an atomic repertoire in that we can tact an indefinite number of arrangements of stimuli to the possible advantage of a listener or to the possible advantage of ourselves at a later time. A radio sportscaster can describe the action of a football game to the satisfaction of fans far away. The repertoire is an atomic repertoire, in the sense used here, if separate elements of a complex context evoke a unique tact so that there is a one-to-one relation between these elements and the verbal response to them. The grain of this atomic repertoire is quite variable and depends, of course, on the details of our discrimination training. Most of us can name objects, but we are often at a loss to describe them in detail, as becomes clear when we are asked to describe someone's face or the details of a crime scene. In contrast, a portrait artist can often tact a person's features with precision.

As we have seen, a main advantage of atomic repertoires is that they permit an instructor or model to cut short the procedure of shaping through successive approximations of a target behavior. But it is unusual to induce someone to engage in verbal behavior by arranging objects in the world to evoke a set of tacts. It is simpler to evoke an echoic or textual response than to evoke a tact of that form. However, as we will see later, tacts can play a special role in inducing novel behavior in combination with other atomic repertoires when there is a delay between an event and our opportunity to respond to that event (i.e., in observational learning).

Miscellaneous Atomic Repertoires

The examples we have considered so far are common to most educated people, but the utility of atomic repertoires extends to any complex behavior in which people are likely to differ widely in skills. In some cases verbal stimuli play no role, and in others the verbal stimuli are arbitrary symbols that are not commonly thought of as verbal. Playing a musical instrument under control of a pattern of notes exemplifies both cases. Many musicians can pick out a

[2] For present purposes, I am including here any behavior that generates consistent units of patterned stimuli. It need not be verbal in Skinner's sense (cf. Catania, 2007, p. 244). A monk might copy a text as he would draw a picture, but his repertoire would not reveal atomic elements until each letter in the text evoked a fluent, consistent response. At this point, although we would still not call his behavior verbal, it would fall under the present analysis, because it would then be possible to evoke in him, without shaping, a great variety of complex patterns of behavior that might serve a second function. To the extent that the repertoire of the skilled artist includes consistent behavioral "atoms," it would also fall under the present analysis. Perhaps the repertoires of caricature artists, cartoonists, and police sketch artists include such atoms.

tune "by ear," a performance analogous to echoic behavior, and most can play notes corresponding to a pattern of dots on a staff. An utter novice instructed in the relation between the notes on a page and the keys of a piano can "pick out the tune," however haltingly. The performance may not delight the music critic, but the important point is that such a performance is a much closer approximation of the target behavior than blind variation at the keyboard. Analogous examples are following a pattern when knitting, weaving, or crocheting; completing connect-the-dot puzzles; following a recipe; painting by numbers; and any other enterprise in which atomic units of behavior are executed solely under instructional control but which, once completed, serve a new function. It takes very little experience or skill to dip a brush in a dish of paint and color in a small bit of canvas that bears a particular number, but that is a common feature of all atomic repertoires. Indeed, that is the point. It takes skill and experience to create the template, but little of either to execute a painting by numbers. Nevertheless, to the casual passerby, the final product is likely to be an acceptable likeness of a landscape or a portrait, as the case may be. More to the point, the artist, such as he is, has just been paced through the motions of making a painting and is far better placed to repeat the performance without the aid of numbers than someone who lacks such experience, because the artist has become somewhat more adept at brush and palette and understands better how to paint shade, light, contrasts, and shapes.

TRANSFER OF CONTROL TO NATURAL CONTINGENCIES

The importance of atomic repertoires is that they facilitate the acquisition of adaptive behavior in a natural context. They permit someone who has already learned how to do something, possibly through laborious experience, to induce that adaptive topography of response in another person rapidly. When the target behavior is emitted under these special conditions, it is commonly reinforced by natural consequences. In the future, that topography of response may have some strength in that context, even in the absence of the specially arranged discriminative stimuli. However, one might suppose that control by instructional stimuli would block control by the context in which sequences of atomic responses are evoked (e.g., Kamin, 1969). Indeed we might get blocking if the only relevant reinforcer were the generalized social reinforcement that typically shapes up atomic repertoires. For example, suppose a telegraph clerk received a message in an unfamiliar language in Morse code. In such a case, the only source of reinforcement would arise from that associated with the atomic transcriptive repertoire, and the clerk would indeed be unlikely to be able to repeat it at a later time under control of contextual stimuli alone. That is, control by the pattern of sounds would block control by the context or by any intraverbal relations. In contrast, if the clerk received a message in his or her native language, a second contingency would become operative. Blocking would not occur because the message was "meaningful"; that is, it would have a source of strength other than its control of transcriptive behavior. It is typically the case that atomic units of behavior are reinforced by natural contingencies. Indeed it is to satisfy these very contingencies that special conditions are arranged to evoke the pattern of behavior in the first place. Thus blocking should rarely occur.

ATOMIC REPERTOIRES AND GENERALIZED OPERANTS

Responses vary from one instance to the next, but nevertheless hang together in orderly response classes;

the reinforcement of one instance will affect the strength of all members of the relevant response class (Skinner, 1935, 1938). For example, in experiments on differential-reinforcement-of-low-rate schedules in pigeons, frequency distributions of interresponse times (IRTs) reveal that the contingency strengthens a range of values, falling off in frequency on either side of a modal value, rather like a Poisson distribution. Many of the IRTs in the class defined by this distribution fall short of the delay criterion. Because they have never been reinforced, it is evident that they have been strengthened by the reinforcement of other members of the class.

Such within-class variability is expected, and it appears to be orderly. However, sometimes the reinforcement of members within such classes leads to the emergence of response forms that fall far outside the boundaries of typical within-class variability. In such cases, we speak of generalized operants (and I propose that this be accepted as the defining property of generalized operants). For example, Baer, Peterson, and Sherman (1967) found that the explicit shaping and reinforcement of a number of imitative responses led to the emergence of some novel imitative responses of different topography without explicit training. Observational learning, generalized identity matching, judgments of similarity, and derived relational behavior are other examples of generalized operant behavior.

There is no doubt that there are empirical phenomena that can be called, for descriptive convenience, generalized operant behavior, but it is not clear how we are to account for the variance in such behavior. Let us take generalized imitation as the paradigmatic case: If we could show that training a certain number of exemplars of imitative behavior, or that training such exemplars to a certain criterion of success, invariably led to generalized imitation, then it would stand as an inductive principle, but this is not the case. Consider a child from the Baer et al. (1967) study, a child in whom generalized imitation had been demonstrated. Now show him Jascha Heifetz playing Paganini on the violin, an acrobat walking a tightrope, or any of a myriad of other examples of complex behavior. Only a child with a special and highly unusual set of atomic repertoires would be able to imitate such performances. A demonstration of generalized imitation does not mean that a child can imitate anything. The explanation for the variance in what will be imitated and what will not be imitated does not lie simply in simple iteration, however long, of exemplar training (e.g., Garcia, Baer, & Firestone, 1971; Young, Krantz, McClannahan, & Poulson, 1994).

If we play a few notes on a piano and give a child a xylophone, he can eventually pick out the tune. The term *eventually* is revealing. The child engages in a series of "trials" and monitors his own "successes and failures" and "recognizes when he is getting close." There is much that is ill defined here, but this is an everyday example that clearly illustrates shaping through automatic reinforcement (see Palmer, 1998, for an extended discussion of such examples). In contrast, if we had played the same notes to a skilled pianist or xylophonist, he or she would have played them back immediately and perfectly, for even if the pattern of notes were wholly novel, the skilled musician has a repertoire of atomic operants that would be evoked by it. These examples suggest the following interpretation: We will see relatively rapid and smooth generalized imitation when the imitator has the requisite atomic repertoire. In other cases, the subject will simply fail to imitate or will fail to try. In still other cases, we will observe a kind of problem-solving behavior that may or may not lead to the shaping of the target behavior over the course of time, a process in which the reinforcer arises from the similarity of the behavior of the model and the behavior being shaped (Baer & Deguchi, 1985; Mowrer, 1952; Palmer, 1996, 1998; Skinner, 1957). Because "similarity" itself is not a stimulus dimension, I have suggested elsewhere that a saltation in response strength arising from joint control may be the critical feature that is common to all judgments of stimulus identity or similarity (Lowenkron, 1998; Palmer, 2010). I am suggesting, then, that generalized imitation is a heterogeneous phenomenon and cannot be understood simply as the product of multiple-exemplar training. (For extended discussions of the many determinants of imitation, see Erjavec & Horne, 2008; Erjavec et al., 2009; Horne & Erjavec, 2007; Lovett, 2008.)

The Role of Atomic Repertoires in Observational Learning

A consideration of atomic repertoires would add little to our conceptual armory if they were not uniquely useful for interpreting certain cases of behavior. The phenomenon of observational learning poses thorny interpretive problems, because it is unclear where response strength comes from. If we observe someone turn on an air conditioner by moving a dial on a wall-mounted thermostat, we will do so ourselves the next time we need to turn on the device, even if we have never done so before. How does the mere act of observing another alter one's behavior at a later time?

Deguchi (1984) noted that standard accounts of observational learning appeal to cognitive mediation (e.g., Bandura, 1977): The model's behavior is encoded into a representation of the behavior; the representation is stored until it is needed; and then it guides subsequent behavior when an appropriate occasion presents itself. Such accounts have been proposed, in part, to fill the gap left by behavior analysts. As Deguchi pointed out, the origins of observational learning are unknown and difficult to explain because, among other things, adaptive behavior in the observer is usually delayed, and it commonly occurs on the first trial when an opportunity for the behavior arises. He suggested that a behavioral account can improve on the standard account by an experimental analysis of extended historical contingencies that includes a consideration of intermittent reinforcement, the role of instructions, and the explicit shaping of overt mediating behavior that can recede to the private level. His suggestions are sound, but I believe a more detailed account is possible: A behavioral interpretation of observational learning that appeals to atomic repertoires offers an explanation without appealing to internal representations or other constructs from another paradigm. The central interpretive task is to explain how stimulus control over the target behavior gets acquired. The model's behavior is under appropriate control of the relevant context; how do the responses come to strength in the observer at a later time under control of an analogous context, apparently in the absence of contingencies of reinforcement?

As I mentioned earlier, when atomic repertoires are evoked by permutations of controlling stimuli, we typically see the appearance of criterion responses on the very first trial of a novel task. The fact that the appearance of adaptive behavior on the first trial is also typical of observational learning suggests that atomic repertoires are being exploited. Much of this behavior may be covert, so our account must be tentative, but if we do not offer a behavioral interpretation, we leave the standard accounts unchallenged.

First, I suggest that, at the time of observation, the observer engages, either overtly or covertly, in tacting, echoic behavior, textual behavior, imitative behavior, or some other atomic responses that are under control of corresponding features of the model. Because the behavior is atomic, it is emitted correctly at once and does not require shaping or repeated trials. Therefore, if we do not have the requisite atomic repertoire, observational learning will not occur. This solves the problem of the origin of the first instance: The target behavior does not appear spontaneously in the observer's repertoire when it is needed; it has occurred in some form at least once before, that is, at the time of observation.

Second, the behavior must be reinforced. This is a necessary assumption, because our account assumes that the behavior will come to strength at a later time under control of the relevant stimuli. As I have argued at greater length elsewhere (Palmer, 2005), this is not an unreasonable assumption. Successfully replicating the behavior of a model, whether or not it leads to a practical benefit in any given case, is likely to be reinforcing, just as failure to do so is likely to be mildly aversive. Successful replication has often led to effective behavior at a later time, whereas failure has led merely to confusion. Motivating variables are relevant: Under conditions of extreme deprivation, aversive stimulation, or other powerful motivating operations, we are much more likely to closely monitor the behavior of an effective model than when we are satiated and at rest.

Third, I suggest that, given appropriate motivating variables, when the context is reinstated at a later time, the atomic repertoire will come to strength. This behavior is either reinforced directly, or it can serve to evoke other behavior that will be reinforced, and our account is complete.

Now let us consider several demonstrations that lend some credence to the above scenario, beginning with the least controversial case: delayed repetition of a verbal response. I routinely demonstrate such behavior in the classroom. "The capital of Uzbekistan," I intone, "is Tashkent." A bit later, when asked for the capital of Uzbekistan, many students respond correctly. Because the response, in most cases, has never been emitted before, it should have no strength at all. However, by postulating that echoic behavior occurred at the time it was modeled, this contradiction is avoided: The response *has* been emitted before, as a covert echoic response. It is revealing that if a student is not "paying attention," he or she will be unable to respond correctly. Listening is behaving; merely hearing is not (Schlinger, 2008). That is, a student who echoes the verbal stimulus will acquire the intraverbal response; a student who fails to echo will not. (It is logically possible that a student could acquire the response by means of mnemonic codes, hand signs, or other alternatives to the echoic, but any such procedure would merely illustrate a different atomic repertoire. In any case, the rule holds: In order for observational learning to occur, the observer must be active.)

Next consider a demonstration in which the atomic repertoires varied across two observers. A model wrote a passage in Russian in the Cyrillic alphabet on a piece of paper. Two observers watched for 15 seconds. One knew no Slavic languages, but the other was a Russian scholar. Somewhat later, they tried to replicate the behavior of the model. The Russian scholar wrote down 101 Cyrillic characters correctly, the other only three. The Russian scholar had two relevant atomic repertoires, a textual repertoire under control of Cyrillic characters and a transcriptive repertoire of Cyrillic characters under control of verbal antecedents. That is, the scholar was able to read the text, recall it later, and reproduce it, presumably under control of her own verbal responses. The other participant, on the other hand, could see the stimuli perfectly well but could make few differential responses to them. His repertoire was altered negligibly by the experience.

The preceding example illustrates an important distinction between a global theory of generalized operants and a more fine-grained interpretation that invokes atomic repertoires: If observational learning is something that just "emerges" because of a long history of successfully following models, then it cannot account for any variance in performance. Both participants had long histories of correctly following models, and both should have been equally successful in replicating the behavior of the model. In contrast, an account in terms of atomic repertoires tracks the variability in this example closely. It is easy to generate many such demonstrations in which differences in atomic repertoires produce differential outcomes in observational learning.

In the following example, the role of atomic repertoires is revealed, not by the nature of the repertoire, but by its grain: A ballerina and I watched a short film clip of a ballet. I could subsequently tact the performance only crudely, whereas she could describe it in exquisite detail, including some slight fault in the performance. Although my tact repertoire is fine grained in some domains, my repertoire with respect to dance movements is coarse.

In some examples of observational learning, it appears that several alternative atomic repertoires come into play. If a relevant imitative repertoire is lacking, tacts and rule-governed behavior can sometimes take over. In a classroom demonstration, I ask students to imitate several simple gestures, which they do easily; then I clasp my hands, fold my arms, and wag two fingers. The modeled behavior is ambiguous, for one can fold one's arms in several ways, and almost no one has had a relevant discrimination history. Consequently, students have no strong imitative responses, and they invariably resort to tacting what they see: "Let's see, your left hand is facing outside, your right inside. You are moving the second finger from your thumb on the left side, which is your right hand. The other finger is next to your little finger on your left hand." They then engage in behavior, not under control of the visual stimulus but under control of their own verbal behavior. In short, the relevant atomic repertoire is not imitative at all but consists of atomic tacts and atomic rule-governed behavior. It is noteworthy that they invariably fail to copy aspects of my behavior that they had failed to tact. Moreover, their ability to execute the behavior depends on the grain of the relevant atomic repertoires: If they cannot tact the behavior with sufficient precision, they are unable to emit it, as when I tap my fingers on the desk rapidly in patterns for which they have no corresponding tact. Thus individual differences in histories of tact training can determine what elements of a performance can be reproduced when the imitative repertoire itself is inadequate.

These everyday examples, which can be generated without limit, all point to a central role of atomic repertoires in observational learning. Our accounts must be tentative, but they offer an alternative to one that invokes encoding, representation, storage, and retrieval. That is, we can offer an interpretation that rests on established behavioral processes and invokes nothing new.

SUMMARY

Natural selection and reinforcement provide parsimonious explanations for complexity in nature, because they can produce adaptive complexity by exploiting blind variability in nature. Human intervention, in the form of genetic engineering or in the form of instructed or modeled behavior, can speed up the two processes by introducing criterion variations abruptly, without waiting for chance processes to offer them up. Repertoires of rule following, imitation, and echoic behavior, among others, provide elementary units of behavior that can be evoked in countless permutations by the corresponding arrangement of discriminative stimuli. Under some conditions, a single pattern of such discriminative stimuli can affect many people at once, over long periods of time. Once emitted, the behavior can be captured by natural contingencies, and instructional control can be dropped. Consequently, human behavior can evolve rapidly and spread rapidly, even in the absence of contingencies that would shape such behavior through the reinforcement of chance variations.

I have also suggested that atomic repertoires are useful interpretive tools for behavior analysts. In particular, they appear to play a role in generalized operant behavior and observational learning, phenomena for which behavioral accounts have been relatively weak. Variability in performance in such tasks can be explained, at least in some cases, by variations in the nature and the grain of atomic repertoires.

Atomic repertoires reach into all facets of our lives: Because they are so efficient in fostering the acquisition of adaptive behavior, the question arises whether differences in the range and grain of these repertoires account for some of the individual differences among people in academic achievement, social skills, work habits, and the many specialized skills that are commonly attributed to special talent, like music, art, and sports. Some atomic repertoires, such as echoic behavior and many instances of imitation and rule following, can be acquired incidentally, but others, such as textual and transcriptive behavior, emerge from systematic cultural contingencies, and it is a principal function of cultures to establish such repertoires. Atomic repertoires in nonhuman species are both uncommon and relatively limited in scope. The relative ease with which many arbitrary topographies of behavior can be induced in our species may account for a substantial amount of the variance between the behavior of humans and that of even our closest relatives.

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